

University of Groningen

Arguments in favour of an anthropogenic origin of Mesolithic pit hearths. A reply to Crombé and Langohr (2020)

Huisman, Hans; Niekus, M.J.L.Th.; Peeters, Hans; Geerts, R.C.A.; Müller, Axel

Published in:
Journal of Archaeological Science

DOI:
[10.1016/j.jas.2020.105144](https://doi.org/10.1016/j.jas.2020.105144)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2020

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Huisman, H., Niekus, M. J. L. T., Peeters, H., Geerts, R. C. A., & Müller, A. (2020). Arguments in favour of an anthropogenic origin of Mesolithic pit hearths. A reply to Crombé and Langohr (2020). *Journal of Archaeological Science*, 119, [105144]. <https://doi.org/10.1016/j.jas.2020.105144>

Copyright

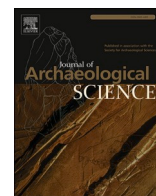
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.



Arguments in favour of an anthropogenic origin of Mesolithic pit hearths. A reply to Crombé and Langohr (2020)

D.J. Huisman^{a,b,*}, M.J.L. Th. Niekus^c, J.H.M. Peeters^b, R.C.A. Geerts^d, A. Müller^d

^a Cultural Heritage Agency of the Netherlands, the Netherlands

^b University of Groningen, Groningen Institute of Archaeology, the Netherlands

^c Stichting STONE/Foundation for Stone Age Research in the Netherlands, the Netherlands

^d ADC ArcheoProjecten B.V., the Netherlands

ARTICLE INFO

Keywords:
Mesolithic
Pit hearths
Ants
Fire

ABSTRACT

In response to the comment by Crombé and Langohr (2020) on our micromorphological study of Mesolithic pit hearths, we argue that these features are most likely anthropogenic in origin, and that it is therefore unlikely that they are the remains of burned ant nests. Arguments for an anthropogenic origin centre around (1) their regional and temporal distribution, (2) their spatial distribution within archaeological sites, (3) their charcoal spectrum and (4) the presence of cultural remains in the pits. We argue that the absence of fire-related features and apparent discrepancies in dating can be attributed to site-formation and taphonomic processes. Finally, we indicate that, due to a lack of actual observations of the subsurface morphology of burned ant nests, it is impossible to make a valid comparison. Based on the existing literature on ant nests fires, we come to a different model of this morphology than do Crombé and Langohr (2020). We conclude that these pit hearths form an important component of the Mesolithic archaeological record and that new research into their formation and their use may shed more light on their origin and purpose.

1. Introduction

The features called pit hearths (or hearth pits) are common in the archaeological record of the Mesolithic of the sandy soils in the Netherlands and adjacent areas of Belgium and Germany. Considerable effort has gone into excavating archaeological sites with large numbers of such pits, and there is an ongoing debate on their formation and their alleged function(s). Significantly, Crombé et al. (2015) and Crombé (2016) proposed that these features are not of anthropogenic origin, but are instead the remains of ant nests (domes) destroyed in forest fires. There have been several large-scale excavations and publications since the publication of this ant nest theory. These include site complexes (e. g., Kampen-Reevediep (Geerts et al., 2018) Hanzelijn-Hattermerbroek (Lohof et al., 2011) and Tunnel Drontermeer (Hamburg et al., 2012)) that had vast numbers of such features, as well as two publications (Peeters and Niekus, 2017; Peeters et al., 2017) presenting overviews on the present state of knowledge about pit hearths. Despite all this analysis, and some discussion in Woltinge et al. (2019), the validity of the ant nest theory has yet to be discussed in detail. The comment by Crombé and Langohr (2020) concerning our paper on the micromorphology of

pit features from Kampen-Reevediep (Huisman et al., 2019) therefore provides a welcome opportunity for a discussion on the ant nest theory as a viable explanation for these pit features. We appreciate the time and effort taken by Crombé and Langohr to include results from our Kampen-Reevediep paper in their discussion. However, in our opinion, the arguments and interpretations provided by Crombé and Langohr (2020) do not support a natural genesis of these features, but instead favour an anthropogenic origin.

In this reply to Crombé and Langohr (2020), we systematically discuss the various issues and arguments supporting an anthropogenic origin of pit hearth features and those supporting the ant nest theory, including those previously mentioned in Crombé et al. (2015) and Crombé (2016). We divide the discussion into three parts. First, we present which properties of the pits indicate an anthropogenic origin. Next, we discuss the reasons why some properties that could be expected in anthropogenic conditions are only rarely observed. Finally, we discuss to what extent the observed properties of Mesolithic pits do or do not match the properties of (burned) ant nests.

* Corresponding author. Cultural Heritage Agency of the Netherlands, the Netherlands.

E-mail address: h.huisman@cultureelerfgoed.nl (D.J. Huisman).

<https://doi.org/10.1016/j.jas.2020.105144>

Received 3 March 2020; Received in revised form 8 April 2020; Accepted 9 April 2020

Available online 7 June 2020

0305-4403/© 2020 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

2. Anthropogenic indicators

2.1. (Supra)regional spatio-temporal patterns

As mentioned in the introduction, the pit hearth phenomenon is generally regarded as typical for the archaeological record of the Mesolithic in the Netherlands and adjacent areas of Belgium and Germany. Most of these features are known from the sandy soils prevalent in the northern half of the Netherlands. Farther to the east and south, their distribution peters out. There is a spatio-temporal dimension to their distribution. The earliest pit hearth features are located in the northern part of their distribution, i.e., the Veenkoloniën ('Peat Colonies'), in the province of Groningen. Farther south, their first appearance in the archaeological record is successively later (see, e.g., Niekus, 2006: Fig. 24; see also Niekus, 2019, for a compilation of the earliest pit hearth dates from the Netherlands).

There are two examples of regional spatio-temporal patterning that are not readily explicable by the ant nest theory; both are briefly discussed in Peeters and Niekus (2017), accompanied by further references. To summarise: Dated pit hearth features from the prehistoric Hunnepe drainage system, in the border area between the Dutch provinces of Overijssel and Gelderland, show a spatio-temporal trend, with the sites with earlier dates situated in the upper part of the Hunnepe system and those with later dates situated in the lower reaches of system. A geographical 'shift' in dates was also observed in the Peat Colonies, where sites in stream valleys along the margins of the area have later Mesolithic (Atlantic) dates and sites in the central part witnessed a clear decline in dates during the early Atlantic (Groenendijk, 1987). An increase in wet conditions (which would be unfavourable for ant nest building) cannot account for this pattern, since peat growth first started long after the Mesolithic (Atlantic), in the Preboreal period (Vos et al., 2018).

Even though these distribution patterns may in part reflect differences in research intensity or interest between regions, it is noteworthy that large numbers of classic pit hearths ('type A' cf. Hamburg et al., 2012) have not been reported from other regions where extensive areas of sandy soils are also present, e.g., Denmark or Great Britain – save a few possible examples, which have not been published in detail (e.g., Brinch Petersen, 1990). We find the apparent lack of these features in those areas, and in particular the lack of dense clusters of these features, difficult to explain within the context of the ant nest theory. Ants will have been present in these areas during the Mesolithic, as will forest fires, and there is no compelling reason to assume that the behaviour of either ants or forest fires will have been different in these regions compared with the regions where the features are found. However, the presence or absence of these features in different regions is more readily explained as a reflection of geographical variability in culture-specific activities by humans. This explanation is strengthened by the fact that the earliest pit hearth features date to the Late Preboreal, roughly around the transition from the Late Palaeolithic to the Mesolithic. Although pit hearth features have been found during excavations of Upper and Late Palaeolithic sites, radiocarbon dating has revealed them to be Mesolithic in age (see e.g., Lanting and Van der Plicht, 1997; for several examples). The fact that there is no substantial presence of pit hearth features on, for example, Federmesser sites – or on those from the Neolithic and later periods – is difficult to explain within the ant nest theory.

2.2. Local and intra-site distribution patterns

Pit hearths are usually found on the tops or (upper) slopes of larger sand ridges, while they are often, but not always, lacking on smaller and lower dunes with flint scatters. Groenendijk (1987) was the first to note the differences in spatial distribution between flint scatters ('domestic zones') and pit hearths on larger hills, such as the site of NP-3, in the Peat Colonies, leading him to suggest that pit hearths were used for

specific activities carried out at some distance from domestic zones. Similar observations with respect to the spatial distribution of pit hearths and flint scatters were also made at the sites of Verrebroek 'Dok 1' (Crombé et al.), Epse-Olthof (Hermesen et al., 2015) and Kampen-Reevediep (Geerts et al., 2018). At Verrebroek, for example, nearly all pit hearths were found on the higher ground in the landscape, at some distance from the dozens of Early Mesolithic artefact scatters; only a few pit hearths were situated near flint scatters. The scarcity or absence of flint artefacts associated with pit hearths can in some cases be explained by the truncation of the original soil profile. However, where flint scatters do occur, pit hearths are still usually rare or absent. The lack of a demonstrable co-occurrence of pit hearths and flint scatters suggests a deliberate spatial layout and provides no support for the ant nest theory. If they were indeed ant nest, one would expect the features we term pit hearths to co-occur with flint scatters as well. Where pit hearths and flint scatters do co-occur, this is more likely to be a function of the extent of the habitable area; if it is relatively small, repeated use would ultimately lead to a palimpsest of different, non-synchronous activities involving pit hearths and flint.

Niekus (2011) and Peeters and Niekus (2017) have already argued that at the site level, pit distribution does not seem to be random. First, a shift was noted in the temporal distribution of pit hearth dates between the sites of NP-3 and S1, in the Peat Colonies (Niekus, 2006:note 21). Both locations are part of a site complex situated on the same coversand ridge. The dates from S1 are, on average, older than those from NP-3, which indicates a shift in Mesolithic activities from west to east. Comparable differences in temporal patterning between different parts (north and south) of the coversand ridge have also been observed at the site of Epse-Olthof (Hermesen et al., 2015).

Second, several recurring spatial configurations have been observed, ranging from single, presumably isolated pit hearths to dense clusters of pits. Within the context of the ant nest theory, the linear configurations could potentially be explained as nests built along a fallen tree trunk. However, the triangular, rectangular and polygonal configurations of pits that occur as well are less easily explained in this way. The same goes for dense clusters of pit hearths, of which there are ample examples, e.g., from the excavations of the sites of Hanzelijn-Hattermerbroek, Tunnel Drontemeer and Kampen-Reevediep (Lohof et al., 2011; Hamburg et al., 2012; Geerts et al., 2018, respectively).

One can argue that it is always possible to discern particular spatial configurations in point-located phenomena, provided they form a dense enough concentration. It is remarkable, however, that there are temporal dimensions present within these configurations as well. For example, radiocarbon dates of features belonging to a single configuration at Epse-Olthof suggest that these features were synchronous within statistical error (Hermesen et al., 2015). Additional examples of configurations with high spatial and chronological integrity are provided by Niekus (2011:Fig. 2, for example). Furthermore, dense clusters of pits (Niekus, 2011) seem to be restricted to the Late Boreal and, even more so, the Atlantic (Late Mesolithic). Such dense clusters are hitherto unknown from Preboreal and earlier Boreal sites. To explain this observed regional variability as being the result of a lower frequency of natural wildfires in this time frame – as would be required to make the data fit the ant nest theory – is unconvincing (see below for further discussion on the frequency of forest fires).

2.3. Charred plant remains in the pits: composition

The ant nest theory builds on established knowledge that ants start to construct their nest in and from dead tree roots and, possibly, trunks, preferably those of pine. Crombé and Langohr (2020:Fig. 1) have schematically visualised their assumptions on how the tree trunk forms the heart of the ant nest, and how subsequent burning leads to the charring of the remaining wood and plant litter and the collapse of the dome. In their model, one would expect to find a particular composition of charred wood (i.e., exclusively that of the tree trunk and roots) and

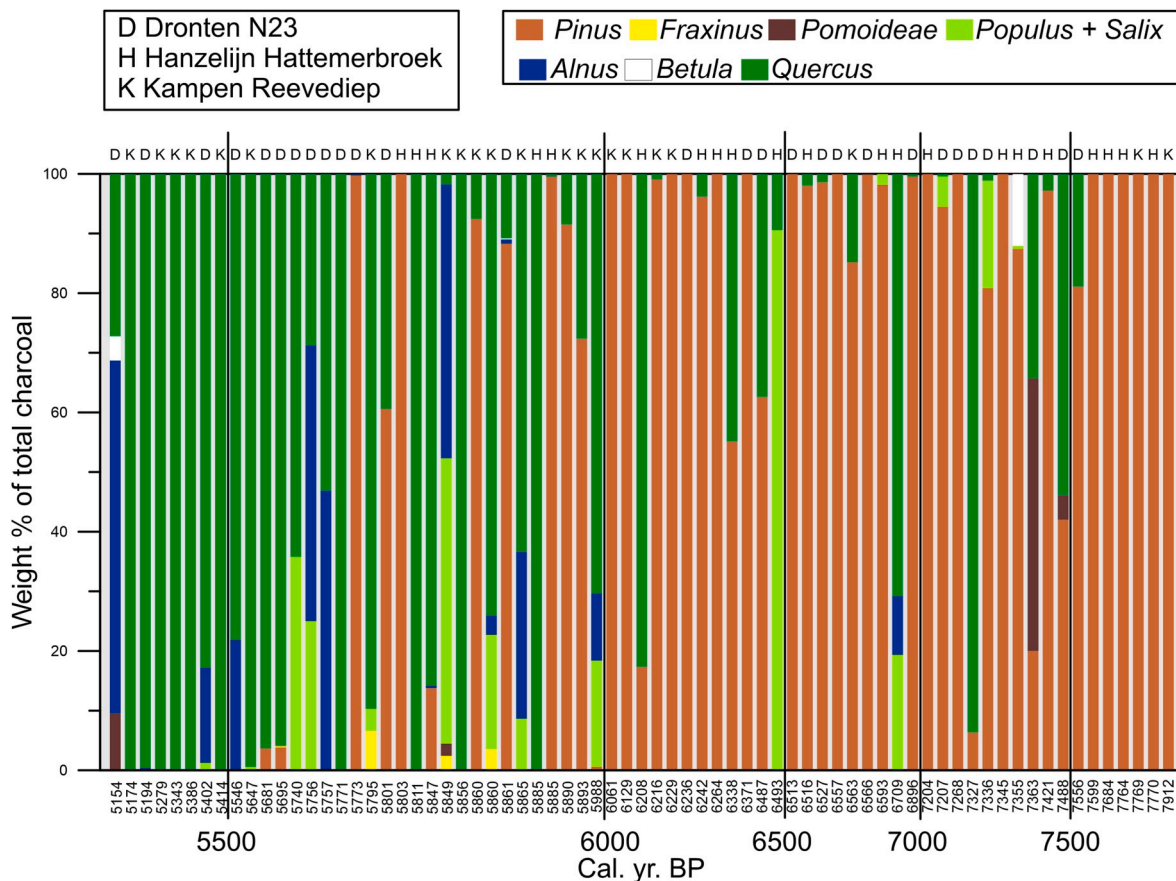


Fig. 1. Overview of the anthracological finds (by weight) from investigated pit hearths at three sites, showing changes in composition through time. Note the frequent occurrence of multiple wood species in one pit, and the presence of charcoal from trees from wet habitats. Data from Kooistra (2011, 2012, 2018).

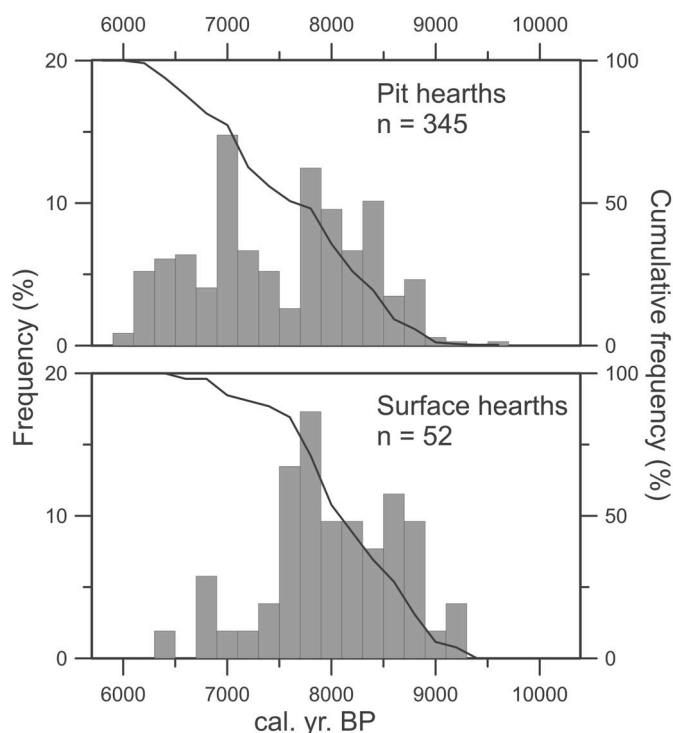


Fig. 2. Frequency and cumulative percentage of uncalibrated radiocarbon dates in 200-year bins. Top: pit hearths; bottom: surface hearths.

other charred plant material (fine fragments of easily transportable material and litter from the undergrowth), resulting from *in situ* burning and charring.

However, the wood represented in the analysed charcoal samples from pit hearths mainly derives from tree trunks, branches and twigs, not roots (Kooistra, 2011, 2012). Trunk and branch wood from all of the frequently represented tree species, also includes those of moist habitats. Apart from one uncertain fragment from Kampen-Reevediep (Geerts et al., 2018), charred roots are absent. The uncharred roots mentioned in several reports (Kooistra, 2011, 2012, 2018) represent younger vegetation and concern fragile fibre material, which probably comes from wetland vegetation that started to grow after the Mesolithic (L. Kooistra, pers. comm. 2019). Hence, indications for *in situ* burning of one of the two categories of tree remnants in which ants might have built their nest (i.e., tree roots) are lacking.

The charcoal spectrum recovered from pit hearths shows a predominance of tree species that one would expect to find with reference to broad models of vegetation history, notably pine (*Pinus sylvestris*) in a Preboreal/Boreal context and oak (*Quercus*) in an Atlantic context. However, anthracological analysis (Fig. 1) found charcoal from multiple wood species in about half of the pits analysed for macro-remains. Out of a combined total of 71 pits analysed from Dronten-N23, Hanzelijn-Hattermerbroek and Kampen-Reevediep, 42 were found to contain charcoal of two to four of the six tree species frequently represented in the charcoal samples (*Pinus*, *Quercus*, *Alnus*, *Salix*, *Betula* and *Pomoideae*). This observation is difficult to reconcile with the ant nest model as illustrated by Crombé and Langohr (2020, Fig. 1): ants. Ants do transport small fragments of plant material but not pieces of wood large enough to leave charcoal after a burning event, and to, additionally, be identified to the taxonomic level of species. In addition, of the five

frequently occurring tree species, *Alnus* and *Salix* in particular grow predominantly in moist habitats, which are unattractive for the construction of ant nests. If the pit features were indeed ant nests, this would require an accumulation process that to us seems highly unlikely: (1) diverse parts of trees belonging to different tree species of different habitats would have needed to accumulate regularly; (2) relatively large fragments of these woods would have needed to accumulate coincidentally in about half of the ant nests; and (3) burning of these nests would have needed to result in charring of these fragments.

The presence of charred remains of species growing in moist habitats is not restricted to woody taxa, such as *Alnus* and *Salix*. Although the number of samples investigated for charred parenchymal remains is still limited, and although not all sampled pits contain such remains, SEM analysis has demonstrated the incidental presence of several aquatic and wetland plant taxa, in addition to dryland species (Kubiak-Martens, 2011; Kubiak-Martens et al., 2012). The occurrence of aquatic and wetland plants, such as *Beta vulgaris*, *Scirpus* and *Typha*, is already difficult to explain within the ant nest theory. Even more problematic to explain is the observation that 33–60% of the charred remains of these plants involves material from the roots and/or stems. Hence, we consider the spectrum of woody and non-woody plant remains – including species from wet habitats – to be a strong indicator for human activity. They occur too systematically to be simply dismissed as ‘intrusion’.

2.4. Cultural remains in the pits

It is difficult to interpret the types and distribution of artefacts in pit hearths, because of issues with representativeness. First, at most sites, the upper part of pit hearths has eroded or was removed unnoticed during excavation. Hence, only the lower horizons of pit hearths were sampled in the majority of cases (cf. Huisman et al., 2019). Second, on sites with lots of pit hearths, only a selection of the pits or only part of the fill of individual pits was sampled. Nevertheless, based on the publications of NP-3, Hanzelijn-Hattermerbroek, Dronten-N23, Epse-Olthof and Kampen-Reevediep (Groenendijk, 1987; Lohof et al., 2011; Hamburg et al., 2012; Hermesen et al., 2015; Geerts et al., 2019; respectively), some general properties of the artefact assemblages can be discerned.

After wood charcoal, flint is the most common anthropogenic material found in pit hearths. Charred hazelnut shells and other types of charred organic matter and burnt bone occur less frequently. It is clear that most of the flint artefacts retrieved from these features are <10 mm and moderately to heavily burnt. Larger artefacts, such as flakes, blades and cores, are relatively rare, as are retouched tools. Heat-cracked cobbles, (fragments of) perforated mace-heads, and other stone tools occur sporadically. The presence of predominantly (small) flint waste has been seen to suggest that some hearths were associated with contemporaneous flint working (e.g., Groenendijk, 1987:91). In our opinion, it is equally possible, however, that this waste resulted from secondary intrusion, as has been argued for charred hazelnut shells, which often return older ^{14}C dates than charcoal originating from the same pit (Crombé et al., 1999; see below). Hazelnut shell and flint debitage are generally associated with surface hearths (Peeters, 2007); their sporadic occurrence in pits may therefore be an indication for the presence of disturbed surface scatters or features nearby. A few examples do exist where a relatively well-preserved small flint scatter and a surface hearth containing charred hazelnut shells seem to be associated with a more or less contemporaneous pit hearth feature (Leek-Mensumaweg [Lanting and Van der Plicht, 1997:139] and Meerstad site 2a [Arnoldussen et al., 2012]).

At some sites, the pits, on average, contain a relatively large number of points, backed blades and products related to their manufacture, such as microburins and retouche chips. At Kampen-Reevediep, nearly half of the retouched pieces from pit hearth features (68 of 138 retouched tools) consist of microliths, backed bladelets, microburins and retouche chips. At Dronten-N23, nearly 77% of the 155 retouched tools from pit hearths

consist of backed bladelets and different types of microliths. These observations might be taken as evidence that pit hearths played a role in the repair or retooling of hunting gear. However, the fact that the Mesolithic surface itself is often missing hampers the comparison of palaeosurface flint assemblages with pit flint assemblages and therefore makes it difficult to interpret the pit content (whether as residual, intrusive or both).

3. Lack of anthropogenic indicators?

3.1. Lack of rubified soil material

Crombé et al. (2015) mention the lack of rubification (reddening of the soil) in the soil underneath the pits – and its presence in surface hearths – as an argument for a non-anthropogenic origin of the features. They state that this lack of rubification indicates that no fire burned in the pits, and that the fire-derived debris in the pits entered the pits afterwards. However, there are other possible explanations for this lack of rubification. Tests with open fires on the ground surface with temperatures >900 °C conducted by Canti and Linford (2000) in most cases did not result in reddening of the soil. These authors mention several factors that may influence the degree of fire-promoted soil reddening, notably moisture content and the properties of the soil iron oxide minerals. In the case of the Mesolithic pit hearths, an additional factor may be that fires were probably oxygen-starved, which may contribute to limited rubification. Physico-chemical analysis of samples from Hanzelijn-Hattermerbroek points to rather low temperatures between 300 °C and 600 °C, while indicators for tar formation – requiring low temperatures and oxygen-starved conditions – have been identified (Kubiak-Martens et al., 2011:504–506). It should also be noted that the presence of charcoal in the pits does not necessarily imply that high-temperature fires were lit in the pits themselves. It is perfectly possible that charcoal was formed in a fire prepared in another location, outside the pit, and then deposited in the pit to provide the heat source for whatever the purpose might have been.

3.2. Decay patterns in wood

Crombé et al. (2015) and Crombé and Langohr (2020) claim that the predominance of decayed, instead of more or less fresh, wood in the charcoal spectrum supports their ant nest theory, under the assumption that decayed branches and trunks at the level of the forest floor formed the basis of a nest prior to its burning. However, Kooistra (2012) interprets this predominance differently; she proposes that partially decayed wood was selected because this would be more suitable for wood tar production. Another interpretation may simply be that dead branches on standing trees – even on trees that are still living – are much easier to ‘harvest’ for firewood. An added bonus would be that this wood would be dry enough to be used immediately.

3.3. Variable ^{14}C dates

An important aspect of the ant nest theory concerns the deviating chronologies of various remains at single sites, notably the observation that the chronology of radiocarbon-dated pits does not coincide with the age of the other cultural remains at the sites, such as flint, charred hazelnut shell or bone (Crombé et al., 2015:165). Crombé and Langohr (2020) go as far as to state that an absence of ‘pit hearths’ is merely an effect of an absence of forest fires. They take the decrease in the number of such pits over the course of the Atlantic, when deciduous forest dominates, as evidence for decreasing wildfire frequency compared with the Preboreal and Boreal, which were dominated by coniferous forests, which are more vulnerable to wildfire.

There is a major problem with regard to the suggested mismatch in the chronology of radiocarbon-dated pit hearths and other cultural remains. The cultural remains are demonstrably associated with surface

hearthths. Such hearthths have been shown to connect to various ‘domestic’ activities, such as flint knapping, tool maintenance, and the cooking and consumption of food. The number of surface hearthths that have been radiocarbon dated is lower than the number of pit hearthths that have been dated, and the radiocarbon date range for the surface hearthths largely overlaps that of the pit hearthths (Fig. 2). This also shows at the scale of individual sites, e.g., at Dronten-N23, for which 96 pit hearth dates and 13 surface hearth dates (all on hazelnut shells) are available. To what extent these dates can be considered contemporaneous in terms of ‘anthropological time’ is impossible to tell due to the statistical limitations of the AMS results. Statistically speaking, however, many of the dates obtained on individual pit hearthths and surface hearthths overlap, and they could very well be of identical age. From the radiocarbon dates, it also is clear that pits occur over a longer stretch of time than do surface hearthths (Fig. 1).

We must remain cautious in interpreting such patterns. Surface hearthths may be underrepresented in the archaeological radiocarbon record, due to criteria used for sample selection and the vulnerability to erosion of remains left on the surface, as well as biases due to excavation strategies.

The suggested decrease in the number of pit hearth dates from the start of the Atlantic onwards (Crombé et al., 2015), does not, in fact, show in the radiocarbon date record. The frequency of dated pits pre- and post-8000 uncal. BP is approximately equal. As stated in the original paper (Crombé et al., 2015) and as restated by Crombé and Langohr (2020), the pits almost disappear from the archaeological record after c. 6000 uncal. BP. In connection with the ant nest theory, these authors suggest that increasingly wet conditions due to structural sea-level rise,

and hence a rise in the groundwater table, would have resulted in a decrease in the frequency of wildfires and a subsequent decrease in the number of ant nests burning down, or even decreased ant activity in these moister areas. However, this does not explain why these pits all but disappear from the archaeological record. There is no reason to assume that ants were no longer active in these areas. Dry forests and dry soil continued to exist in the Neolithic – also outside the Netherlands. Moreover, as Vannière et al. (2016) and Feurdean et al. (2017) show, although forest fire frequency is influenced by the type of forest as well as by climate and human behaviour, such fires do not disappear completely.

4. What about ants?

A major problem in the present discussion is that we lack systematic documentation of the morphology of ant nests, and especially of the effects of burning on such nests. Many of the similarities between the Mesolithic pit features and ant nests (including those presented by Crombé and Langohr, 2020:Fig. 1) are therefore based on *assumed* properties of these nests, which are then argued to be similar to those of (‘type A’) pit hearthths. But they do not present actual observations on the subsurface morphology of burned ant nests. The sparse information on the (subsurface) construction of NW European ant nests and the impact of wildfires (Boer, s.d.; Boer and Kelder, 2016; Kristiansen and Amelung, 2001; Kristiansen et al., 2001), however, suggests a different morphology of ant nests – whether active or burned – than do Crombé and Langohr (2020). The schematic cross section of a *Formica polyctena* nest presented in Kristiansen and Amelung (2001:Fig. 2) and reproduced

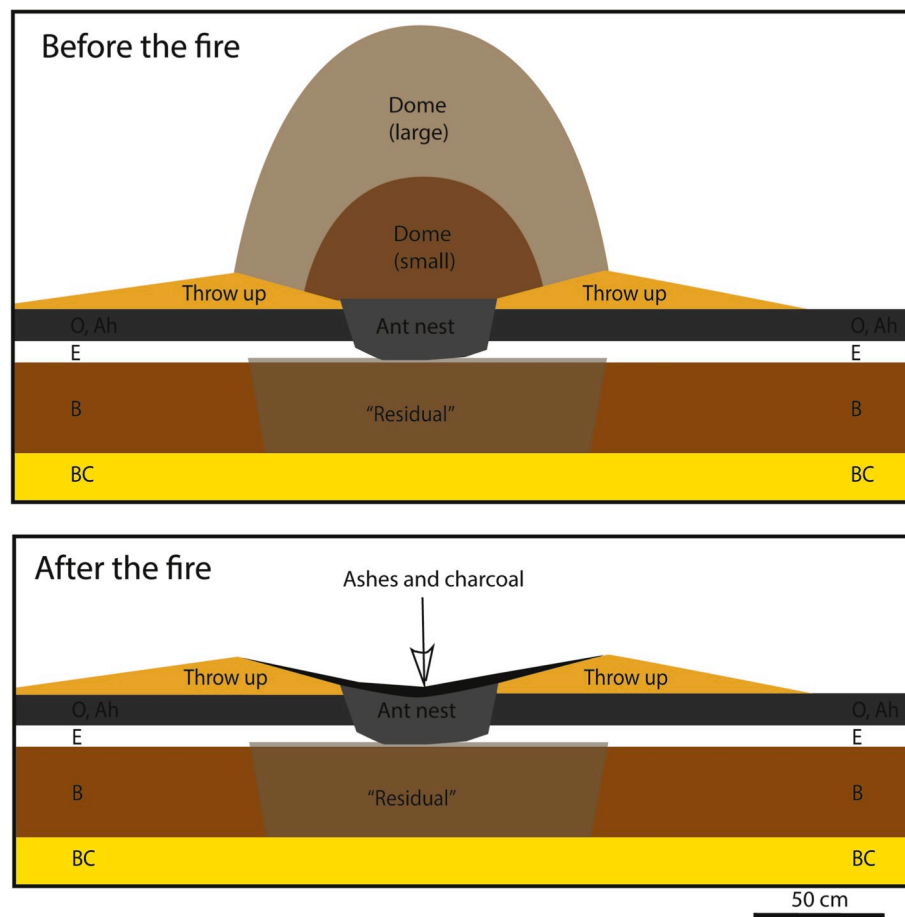


Fig. 3. Schematic cross section through a nest of a species of red forest ant (*Formica polyctena*), based on Boer (s.d.), Boer and Kelder (2016), Kristiansen and Amelung (2001) and Kristiansen et al. (2001). The superstructure (or dome) may vary in shape, and it may or may not incorporate the surrounding earthen wall. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

in Crombé et al. (2015) seems to be an oversimplification of the profiles of burnt or abandoned ant nests in Kristiansen and Amelung (2001: Fig. 3). Based on Kristiansen and Amelung (2001: Fig. 3) and the photographs in Boer (s.d.) and Boer and Kelder (2016) of a burnt *Formica rufa* nest, we derived a different general cross section (see Fig. 3).

Forest ant nests of such species as *Formica polyctena* and *Formica rufa* have a superstructure that mostly consists of organic material, notably pine needles and other organic litter. This structure continues some 10 cm into the subsoil. Nests may incorporate trees or tree stumps, but this is by no means always the case. If (dead) tree stumps, branches or other wood fragments are incorporated into an ant nest, this wood usually shows evidence of intensive tunnelling by ants – something not commonly seen in pit hearth charcoal. Mineral material from the deeper soil horizons may be incorporated in the nest structure, but this material is mainly deposited as a wall surrounding the nest proper. Underneath the superstructure is the buried nest, described as ‘residual’ horizons by Kristiansen and Amelung (2001) and Kristiansen et al. (2001), which may reach depths of up to 40 cm. These horizons essentially consist of the original podzol B (h,s,t), or BC horizons and are intensively tunnelled with galleries and chambers. Little to no vegetative litter is deposited in these residual horizons, and organic carbon concentrations do not exceed 1% – i.e., organic matter contents are < c. 2.5% (Kristiansen and Amelung, 2001; Kristiansen et al., 2001). Tunnelled B or BC horizons have not been observed in relation to pit hearth features. Sediment with such a low carbon content as documented in the residual horizon is highly unlikely to burn, let alone be consumed and leave a deep crater, as suggested by the ant nest theory.

Field observations confirm that, in the case of wildfire, the organic-rich superstructure of ant nests readily burns away. However, the underlying, residual horizons do not burn; Boer (s.d.) and Boer and Kelder (2016) describe what they term a volcano crater-like remnant of mineral soil material that is left at the surface after a fire. They also indicate that in the deep nests, such as the ones made by *Formica rufa*, the sub-surface galleries and chambers remain cool enough for the queen and some of the worker ants to survive, and to show activity at the surface within a few days after the fire. During such fires, it is uncommon for tree trunks, roots and other relatively voluminous wood remains to turn into charcoal. Rather, charring is restricted to bark and wood surfaces (Boer, s.d.; Boer and Kelder, 2016), due to the short duration of such fires. These field observations do not match the observed charcoal-rich deposits in the Mesolithic pit hearths, and especially the occurrence of charred logs in some of them.

In the original paper (Crombé et al., 2015), chemical data were presented that were said to support the ant nest theory. Most important in the discussion were the concentrations of phosphorus (P) and of the exchangeable bases (Ca, Mg, K, Na). Whereas Crombé et al. (2015) attribute elevated concentrations of P to indicators for ant activity – ants being carnivorous – we argue that it is equally or more plausible to attribute it to the elevated concentrations of charcoal, which is known to be enriched in P (cf. Wilson et al., 2009).

Furthermore, as already indicated in Crombé et al. (2015), for the site of Verrebroek, the exchangeable base composition is likely to have suffered considerable post-depositional alteration, due to interaction with changing groundwater composition, especially when inundations resulted in salinisation processes. Therefore, it is especially hazardous to interpret these chemical properties of archaeological features in sandy soils in areas where changes in the groundwater regime may have caused degradation and/or alteration of the ‘original’ chemical footprint. This is the case in many parts of the Netherlands, as well as in the western lowlands of Belgium, where Verrebroek is located. Therefore, these chemical data are not amenable to establishing the origin of the pit features discussed here.

5. Synthesis and conclusion

In the discussion on the origin of the Mesolithic pit hearth features, a

number of different observations and interpretations are of relevance. The overview of these observations and interpretations as outlined in this Reply, in our opinion, has yielded no arguments that unequivocally indicate a natural origin of the Mesolithic pit features. The distribution in time and space; the shape of the pits; and the pit contents (including fire-cracked flint, charred logs, charred wetland plants, multiple wood species in charcoal from single pits, to name only a few), among other properties, are compelling indicators that we are dealing with anthropogenic features.

Another important point to reiterate is that Crombé et al. (2015) and Crombé and Langohr (2020) compare the pit features with assumed properties of burnt ant nests. No burnt ant nest has yet been investigated and described in such a way that a rigorous comparison can be made. This includes the authors’ illustration (Crombé and Langohr, 2020: Fig. 1), which is based on conjecture, rather than on actual observations. As we note above, our paper on the Kampen-Reevediep pits (Huisman et al., 2019) has provided additional information on basic properties and formation processes of these pits. However, much still remains obscure with respect to the purpose and technical functioning of these structures. To elucidate their purpose and their functioning, more targeted archaeological and scientific research is needed, including experimental setups.

Equally important is Crombé et al.’s (2015) implicit suggestion that the lack of contemporaneous settlement debris in zones with pit features has important conceptual implications. The position they take, in fact, implies that archaeological evidence for hunter-gatherer activity can only be established for situations where we have settlement debris, notably scatters of lithics and/or other cultural remains. The corollary of this position would be that any phenomenon that does not meet one or more of these conditions is to be rejected as being archaeological in origin, thus potentially eliminating aspects of hunter-gatherer behaviour that do not directly involve ‘settlement’ or ‘domestic’ activity. In our opinion, to accept this position would be a move in the wrong direction.

Based on the current evidence, we maintain our view that the Mesolithic pit hearth features are of anthropogenic origin. Apart from a superficial similarity with the assumed morphology of burnt ant nests, there is no solid basis for interpreting these features as natural phenomena. Contrary to the opinion expressed by Crombé et al. (2015:169), we value the excavation, documentation and analysis of pit hearth features, since they form an integral part of the Mesolithic archaeological record. The present discussion makes clear that the interpretation of the pit hearth phenomenon involves many aspects, and that, depending on how one interprets them, some of these aspects can lead to opposing opinions about its nature. We hope that our paper on the Kampen-Reevediep pits, and the subsequent comments and reply, trigger further research, either to support the ant nest theory or to develop insight into the functional nature of such pits as manifestations of human behavioural diversity.

Declaration of competing interest

We declare no conflict of interest.

Acknowledgements

We would like to thank Laura Kooistra for providing the charcoal species data, and Suzanne Needs for language checking and corrections.

References

- Arnoldussen, S., Mendelts, J.P., Fens, R.L., Peeters, J.H.M. (Eds.), 2012. Een Mesolithische Kampement Te Meerstad: Vindplaats 2a. Rijksuniversiteit Groningen, Groningen (Grondsporen 12).
- Boer, P., s.d. Kwetsbaarheid van mieren voor brand [Vulnerability of ants to fire; in Dutch] [last visited 31-10-2019]. http://www.nlmieren.nl/IMAGES/brand_dui_nbrand_comp.pdf.

- Boer, P., Kelder, L., 2016. Effecten van brand, kaalkap en verstuiving op Rode bosmieren [Effects of fire, clear-cutting and wind erosion on red forest ants. Dutch]. De Levende Natuur, March, pp. 61–64.
- Brinch Petersen, E., 1990. Vaenget Nord: excavation, documentation and interpretation of a Mesolithic site at Vedbaek, Denmark. In: Bonsall, C. (Ed.), The Mesolithic in Europe. John Donald Publishers, Edinburgh, pp. 325–330.
- Canti, M.G., Linford, N., 2000. The effects of fire on archaeological soils and sediments: temperature and colour relationships. *Proc. Prehist. Soc.* 66, 385–395.
- Crombé, Ph., 2016. Forest fire dynamics during the early and middle Holocene along the southern North Sea basin as shown by charcoal evidence from burnt ant nests. *Veg. Hist. Archaeobotany* 25, 311–321.
- Crombé, Ph., Langohr, R., Louwagie, G., 2015. Mesolithic hearth-pits: fact or fantasy? A reassessment based on the evidence from the sites of Doel and Verrebroek (Belgium). *J. Archaeol. Sci.* 61, 158–171.
- Crombé, Ph., Langohr, R., 2020. On the origin of Mesolithic charcoal-rich pits: a comment on Huisman et al. *J. Archaeol. Sci.* (this issue).
- Crombé, Ph., Perdaen, Y., Sergeant, J., s.d. Features. In: Crombé, Ph. (Ed.), The Last Hunter-Gatherer- Fishermen in Sandy Flanders (NW Belgium): the Verrebroek and Doel Excavation Projects, Part 1: Palaeo-Environment, Chronology and Features. Academia Press, Gent (Archaeological Reports Ghent University 3), pp. 141–179.
- Crombé, Ph., Groenendijk, H., van Strydonk, M., 1999. Dating the Mesolithic of the low countries: some methodological considerations. In: Actes du 3ème Congrès International 14C et Archéologie. Lyon, Société Préhistorique Française (Mémoires de la Société Préhistorique Française, XXVI & Supplément 1999 de la Revue d'Archéométrie), pp. 57–63.
- Feurdean, A., Veski, S., Florescu, G., Vannière, B., Pfeiffer, M., O'Hara, R.B., Stivirs, N., Amon, L., Heinsalu, A., Vassiljev, J., Hickler, Th., 2017. Broadleaf deciduous forest counterbalanced the direct effect of climate on Holocene fire regime in hemiboreal/boreal region (NE Europe). *Quat. Sci. Rev.* 169, 378–390.
- Geerts, R.C.A., Müller, A., Niekus, M.J.L.Th., Vermue, F.J. (Eds.), 2018. Mesolithische kampen onder de oever van het Reevediep: een archeologische opgraving van vindplaats 9 in het tracé van de hoogwatergeul in het Reevediep te Kampen. ADC-Archeoprojecten, Amersfoort (ADC Monografie 26).
- Groenendijk, H.A., 1987. Mesolithic hearth-pits in the Veenkoloniën (prov. Groningen, The Netherlands): defining a specific use of fire in the Mesolithic. *Palaeohistoria* 29, 85–102.
- Hamburg, T., Müller, A., Quaddlieg, B. (Eds.), 2012. Mesolithisch Swifterbant: mesolithisch gebruik van een duin ten zuiden van Swifterbant (8300–5000 v. Chr.): een archeologische opgraving in het tracé van de N23/N307, provincie Flevoland. Archol & ADC-Archeoprojecten, Leiden & Amersfoort (Archol report 174 & ADC report 3250).
- Hermesen, I., van der Wal, M., Peeters, J., 2015. Afslag Olthof: archeologisch onderzoek naar de vroegprehistorische vindplaatsen op de locaties Olthof-Noord en Olthof-Zuid in Epse-Noord. Archeologie Deventer. Deventer (Rapporten Archeologie Deventer 34).
- Huisman, D.J., Niekus, M.J.L.Th., Peeters, J.H.M., Geerts, R.C.A., Müller, A., 2019. Deciphering the complexity of a 'simple' Mesolithic phenomenon: indicators for construction, use and taphonomy of pit hearths in Kampen (The Netherlands). *J. Archaeol. Sci.* 109, 104987.
- Kristiansen, S., Amelung, W., 2001. Abandoned anthills of *Formica polyctena* and soil heterogeneity in a temperate deciduous forest: morphology and organic matter composition. *Eur. J. Soil Sci.* 52, 355–363.
- Kristiansen, S., Amelung, W., Zech, W., 2001. Phosphorus forms as affected by abandoned anthills (*Formica polyctena* Förster) in forest soils: sequential extraction and liquid-state ³¹P-NMR spectroscopy. *J. Plant Nutr. Soil Sci.* 164, 49–55.
- Kubiak-Martens, L., 2011. Voedselconomie: parenchym en andere plantaardige macroresten. In: Lohof, E., Hamburg, T., Flamman, J. (Eds.), Steentijd opgespoord: archeologisch onderzoek in het tracé van de Hanzelijn-Oude Land. Archol & ADC-Archeoprojecten, Leiden & Amersfoort (Archol report 138 & ADC report 2576), pp. 465–482.
- Kubiak-Martens, L., Kooistra, L.I., Langer, J.J., 2011. Mesolithische teerproductie in hattermerbroek. In: Lohof, E., Hamburg, T., Flamman, J. (Eds.), Steentijd opgespoord: archeologisch onderzoek in het tracé van de Hanzelijn-Oude Land. Archol & ADC-Archeoprojecten, Leiden & Amersfoort (Archol report 138 & ADC report 2576), pp. 497–512.
- Kubiak-Martens, L., Langer, J.J., Kooistra, L.I., 2012. Plantenresten en teer in haardkuilen. In: Hamburg, T., Müller, A., Quaddlieg, B. (Eds.), Mesolithisch Swifterbant: mesolithisch gebruik van een duin ten zuiden van Swifterbant (8300–5000 v. Chr.): een archeologische opgraving in het tracé van de N23/N307, provincie Flevoland. Archol & ADC-Archeoprojecten, Leiden & Amersfoort (Archol report 174 & ADC report 3250).
- Kooistra, L.I., 2011. Houtskool en houtgebruik. In: Lohof, E., Hamburg, T., Flamman, J. (Eds.), Steentijd opgespoord: archeologisch onderzoek in het tracé van de Hanzelijn-Oude Land. Archol & ADC-Archeoprojecten, Leiden & Amersfoort (Archol report 138 & ADC report 2576), pp. 483–495.
- Kooistra, L.I., 2012. Houtskool uit mesolithische kuilen. In: Hamburg, T., Müller, A., Quaddlieg, B. (Eds.), Mesolithisch Swifterbant: mesolithisch gebruik van een duin ten zuiden van Swifterbant (8300–5000 v. Chr.): een archeologische opgraving in het tracé van de N23/N307, provincie Flevoland. Archol & ADC-Archeoprojecten, Leiden & Amersfoort (Archol report 174 & ADC report 3250).
- Kooistra, L.I., 2018. Appendix IV: houtskool. In: Geerts, R.C.A., Müller, A., Niekus, M.J.L.Th., Vermue, F.J. (Eds.), 2018. Mesolithische kampen onder de oever van het Reevediep: een archeologische opgraving van vindplaats 9 in het tracé van de hoogwatergeul in het Reevediep te Kampen. ADC-Archeoprojecten, Amersfoort, pp. 353–380 (ADC Monografie 26).
- Lanting, J.N., Van der Plicht, H., 1997/1998. De ¹⁴C-chronologie van de Nederlandse pre- en protohistorie, II: Mesolithicum. *Palaeohistoria* 39/40, 99–162.
- Lohof, E., Hamburg, T., Flamman, J., 2011. Steentijd opgespoord: archeologisch onderzoek in het tracé van de Hanzelijn-Oude Land. Archol & ADC-Archeoprojecten, Leiden & Amersfoort (Archol report 138 & ADC report 2576).
- Niekus, M.J.L.Th., 2006. A geographically referenced ¹⁴C database for the Mesolithic and the early phase of the Swifterbant culture in the northern Netherlands. *Palaeohistoria* 47/48, 41–99, 2005/2006.
- Niekus, M.J.L.Th., 2011. Ruimtelijke configuraties van mesolithische haardkuilen in Noord-Nederland. *Paleo-aktueel* 22, 16–23.
- Niekus, M.J.L.Th., 2019. The 'Dark ages': a brief survey of the late preboreal and earlier boreal occupation in The Netherlands. In: Fagnart, J.-P., Weber, M.-J., Valentin, B., Mevel, L. (Eds.), Proceedings of the 28th Congrès préhistorique de France in Amiens (Préhistoire de l'Europe du Nord-Ouest: mobilité, climats et identités culturelles): Volume 2: Paléolithique supérieur ancien, Paléolithique final – Mésolithique: Session 3: L'Europe du Nord-Ouest autour de 10.000 BP (11.600 cal. BP): Quels changements? [Northwestern Europe around 10.000 BP (11.600 cal. BP): Which changes?; in French] Séances de la Société Préhistorique Française, pp. 417–432.
- Peeters, J.H.M., 2007. Hoge Vaart-A27 in context: towards a model of Mesolithic-Neolithic land-use dynamics as a framework for archaeological heritage management. In: Rijksdienst voor Archeologie, Cultuurlandschap en Monumenten, Amersfoort.
- Peeters, J.H.M., Raemaekers, D.C.M., Devriendt, I.I.J.A.L.M., Hoebe, P.W., Niekus, M.J.L.Th., Nobles, G.R., Schepers, M., 2017. Paradise lost? Insights into the early prehistory of the Netherlands from development-led archaeology. *Cultural Heritage Agency of the Netherlands, Amersfoort*, p. 259. https://cultureelerfgoed.nl/sites/de-fault/files/publications/nar62.paradise_lost.pdf.
- Peeters, H., Niekus, M.J.L.Th., 2017. Mesolithic pit hearths in the northern Netherlands. Function, time-depth, and behavioural context. In: Acharé-Corompt, N., Ghesquière, E., Riquier, V. (Eds.), *Creuser au Mésolithique/Digging in the Mesolithic*. Actes de la séance de la Société préhistorique française de Châlons-en-Champagne (29-30 mars 2016). Paris, Société préhistorique française, 2017 (Séances de la Société préhistorique française, 12), pp. 225–239.
- Vannière, B., Blarquez, O., Rius, D., Doyen, E., Brücher, T., Colombaroli, D., Connor, S., Feurdean, A., Hickler, T., Kaltenrieder, P., Lemmen, C., Leys, B., Massa, C., Olofsson, J., 2016. 7000-year human legacy of elevation-dependent European fire regimes. *Quat. Sci. Rev.* 132, 206–212.
- Vos, P.C., van der Meulen, M.J., Weerts, H.J.T., Bazelmans, J., 2018. Atlas van Nederland in het Holoceen: landschap en bewoning vanaf de laatste ijstijd tot nu. Prometheus, Amsterdam.
- Wilson, C.A., Davidson, D.A., Cresser, M.S., 2009. An evaluation of the site specificity of soil elemental signatures for identifying and interpreting former functional areas. *J. Archaeol. Sci.* 36 (10), 2327–2334.
- Woltinge, I., Opbroek, M., Tebbens, L.A., Devriendt, I., Drenth, E., 2019. Mesolithisch verblijf en marettakspitsen aan de Staringlaan te Soest: de opgraving van een mesolithische 'persistent place'. BAAC, 's-Hertogenbosch (BAAC rapport A-15.0124, 2 vols.).